SECTION III

MORBIDITY AND AIR POLLUTION

PROBLEMS AND OBJECTIVES

A great number of epidemiological studies have suggested that there is a significant relationship between various morbidity rates and air pollution. Even in the early 17th century it was quite generally suspected that sulfur dioxide in coal smoke was responsible for the high morbidity and mortality associated with the notorious smoke disasters such as those that later occurred in Belgium's Meuse Valley in 1930, in Donora, Pennsylvania in 1948 and in London in 1952.

The relationship between air pollution and health can be acute response--dramatic increases in air pollution concentration exert an immediate adverse effect on human health. However, it is well known that air pollutants continuously react dynamically in the environment. The effect of pollutants on health should also be examined over an extended period. Lave and Seskin (1973b, p. 17) remarked that "a long, or chronic exposure to low concentrations might be just as harmful to health as a short, or episodic exposure to high concentrations."[1/]

The diseases which are known to be related to air pollution include the following: bronchitis and emphysema; pneumonia, tuberculosis and asthma; total respiratory diseases; lung cancer; nonrespiratory-tract cancers; and cardiovascular diseases. A review of the existing literature on the diseases attributable to air pollution is given in the following paragraphs for better understanding of the problems under study.

Bronchitis and Emphysema

Six specific bronchitis rates have been found by Stocks (1959) to be correlated with a deposit index and smoke. This result was corroborated by Ashley (1969) who found a positive correlation between deaths due to bronchitis and sulfur dioxide and smoke. However, a contrary result was obtained by Burgess and Shaddick (1959) who failed to reveal a significant relationship between bronchitis death and air pollution.

Holland and Reid (1965) and Reid (1968) found that the health status of postmen was inversely affected by fog and air pollution. Cornwall and Raffle (1961) found a positive correlation between sickness absence and fog.

1/ A comprehensive literature review on the effect of air pollution on human health was provided, for example, by Lave and Seskin (1975).

Higgins (1966) found lower peak expiratory flow rate in urban areas than in rural areas. Hammond (1967) confirmed that heavy smokers in cities suffered a much higher morbidity rate than those in the rural areas. Ishikawa et al. (1969) found that the incidence and severity of emphysema was higher in St. Louis than in Winnipeg, which had a lower pollution level than St. Louis.

Petrilli et al. (1966) also discovered that the incidence of bronchitis was signficantly correlated with pollution. Toyama (1964) and Yoshida et al. (1966) confirmed the positive relationship between bronchitis and pollution.

Pneumonia, Tuberculosis, and Asthma

Stocks (1960) discovered a high correlation between smoke index and pneumonia mortality. Mills (1943) found substantial correlation between pneumonia mortality and pollution levels. Significant sample correlations for pneumonia mortality and fuel consumption, and for tuberculosis mortality and fuel consumption were reported by Daly (1969).

Sultz et al. (1969) found a significant relation between air pollution levels and the incidence of asthma and eczema among boys under 5 years of age. Yoshida et al. (1969) found that bronchial asthma among Japanese residents was proportional to the sulfur dioxide levels.

Total Respiratory Disease

Skalpe (1964) found that pulp mill workers under 50 years of age exposed to sulfur dioxide suffered from a significantly lower maximal expiratory flow rate. Speizer and Ferris (1963) reported more prevalent chronic respiratory disease in those working in the tunnel for more than 10 years than for those with shorter employment periods.

Winkelstein and Kantor (1969) discussed a positive reaction between cough with phlegm and suspended particulates. However, the association was not found between cough and sulfur dioxide. Rosenbaum (1961) found that British servicemen from an industrial region exhibited a greater liability to respiratory diseases.

Feidbert et al. (1967) discovered that total respiratory disease mortality in Nashville was directly related to the degree of sulfation and soiling. Lepper et al. (1969) found that total respiratory deaths were related to the levels of sulfur dioxide across areas of Chicago with various socioeconomic variables being controlled.

Lung Cancer

Dean (1966) discovered that lung cancer death rates are higher in urban areas than in rural areas. Gardner et al. (1969) found the lung cancer death rate in males is positively related to air pollution when other social and environmental factors are controlled. Somewhat inconsistent results regarding the relationship between sulfur dioxide and lung cancer were obtained by Buck and Brown (1964).

Stocks (1966) discovered a significant correlation between lung cancer and air pollution. Clemmesen and Nielsen (1951) reported the lung cancer morbidity for males in Copenhagen was about four times greater than in rural areas in Denmark.

Manos and Fisher (1959) and Griswold et al. (1955) found that urban lung cancer rates are significantly higher than rates in rural or nonmetropolitan areas. Greenburg et al. (1967) reported correlation between lung cancer and air pollution. However, negative results were obtained by Zeidberg et al. (1967) and Winkelstein et al. (1967).

Nonrespiratory-Tract Cancers and Cardiovascular Disease

Winkelstein and Kantor (1969) found that stomach cancer mortality was twice as high in high pollution areas as in low pollution areas.

Levin et al. (1960) discovered that the incidence rate for both sexes for each of 16 categories of cancer was higher in urban than in rural areas. Contrary results have also been reported by Greenburg et al. (1967a), among others.

Higher incidence rates of cardiovascular diseases in urban than in rural areas were reported by Enterline et al. (1960). Zeidberg et al. found heart disease rates were correlated with air pollutants in Nashville. Manos and Fisher (1959) also found positive relationships between heart disease and air pollution.

The results of many of the epidemiological studies discussed above indicate that incidence rates of various kinds of diseases are generally much higher in the urban areas than in the rural areas. Many of these disparities in morbidity rates between urban and rural areas can be attributed to air pollution. The ratio of urban incidence to rural incidence of morbidity has been termed the urban factor. This urban factor has been used for estimating health damage due to air pollution. The rationale for the urban factor technique is that if air pollution levels in the urban areas could be reduced to the rural levels, then the differences between the urban and rural morbidity rates adjusted for smoking, age, sex, and race should be eliminated.

The crucial question is what portion of this urban factor is attributable to air pollution. In a pioneering study of air pollution damage, Ridker (1965) assumed that 100 percent of the urban factor is attributable to air pollution and derived a damage value of $2 billion for 1958. Williams and Justus (1974) assumed that a minimum of 10 percent and a maximum of 50 percent of the urban factor is due to air pollution and estimated that the total 1970 nationwide health cost due to air pollution was between $62 million and $311 million. The figures are much lower than the estimate of $6.22 billion for respiratory disease in the United States.1/ The damage estimates derived by using the urban factor of health deterioration due to air pollution are apparently subject to a large margin of error because of the difficult assignment problem of the urban factor. The urban factor method is also replete with several other conceptual and practical difficulties. For example, the distinction between urban and rural pollution levels is hard to define because there exists a continuous scale of pollution intensity instead of a simple dichotomy between urban and rural pollution levels. Thus, after all, the question as to what percentage of this urban factor is actually accounted for by air pollution remains largely unresolved.

A recent study performed by Shy et al. (1974) on the Community Health and Environmental Surveillance System (CHESS) examined the adverse effects of air pollution on acute and chronic respiratory disease. The methodological procedures employed in the CHESS study involve statistical analysis with varying pollutant gradients and concentration levels. Each CHESS set which consists of a group of communities selected to represent an exposure gradient for designated pollutants generally includes High, Intermediate, and Low exposure communities. The community selection is subject to the following criteria: The communities have similar climates and are made up of a predominantly white, middle-class population with as much homogeneity in socioeconomic and other demographic factors as possible. The research findings point to a clear trend toward excess illness in the High exposure community.

Since the national and regional annual damage cost figures greatly assist policymakers in determining optimal pollution control strategies, the effort to derive a set of internally consistent and relatively accurate damage estimates is warranted. The primary purpose of this study is to derive such damage estimates. Specifically, physical and economic damage functions will be derived relating morbidity rate and morbidity costs to air pollution, socioeconomic, demographic, and climatological variables. The morbidity damage costs will be estimated for the 40 SMSA's included in the preceding section on mortality and air pollution.

The balance of this section, which represents an exploratory effort to estimate morbidity dose-response functions for adult morbidity damage costs for the 40 SMSA's selected in our study, discusses the following subjects:

1/ For a detailed discussion on some of the problems in using the urban factor for calculating health costs, see J. R. William and C. F. Justus, "Evaluation of Nationwide Health Costs of Air Pollution and Cigarette Smoking," Journal of the Air Pollution Control Association (November 1974), pp. 1063-1066. The figure $6.22 billion was derived by William and Justus by adjusting Ridker's value of $2 billion for 1958.

Environmental Damage Functions: Some Theoretical Underpinnings, Adult Morbidity and Air Pollution, Adult Morbidity Damage and Sulfur Dioxide, Economic Damages and Economic Damage Functions, and Adult Morbidity Damages and Total Suspended Particulates.

ENVIRONMENTAL DAMAGE FUNCTIONS: SOME THEORETICAL UNDERPINNINGS

An economic damage function, which is usually derived on the basis of a physical damage function, is defined, for example, by Maler (1974) as the compensating variation or the amount the individual (or society) should be compensated so as to maintain his initial preference level in the presence of a deterioration in the environment. This definition is clearly applicable to any situations in which the effect of environmental degradation enters directly into the individual's utility function.

We assume that the consumer's preferences can be represented by a twice differentiable, concave utility function, defined on R^{m+n}

$$U = U(C,H(A)) \qquad \text{(III-1)}$$

where C is an m-vector representing m private commodities and services, with positive components indicating consumption, and negative ones, supply of labor services. H denotes the health status, which is influenced by air pollution; A is an n-vector characterizing environmental quality, which is exogeneously given to the community. H can be viewed as the dose-response function.

Each individual wants to maximize (III-1) subject to the following budget constraint:

$$PC \leq Y \qquad \text{(III-2)}$$

where P is the price vector associated with C, and Y is the individual's income.

The economic damage function as registered in the compensation variations due to changes in the individual's health condition because of changes in A can be derived by minimizing the total expenditures subject to a given utility level, say $\tilde{U}$.

The familiar first order necessary conditions are

$$\alpha U_i = P_i, \; i = 1,\ldots,m \tag{III-3}$$

where α is the Langrangean multiplier.

Solving (III-3) yields the following compensated demand functions

$$C = C(P,H(A);\bar{U}) \tag{III-4}$$

The minimum income required to maintain the same utility level when one or several components in A changes is denoted by[1/]

$$I = I(P,A;\; \bar{U})$$

Assuming the individual always exhausts his budget, the economic damage function is simply the difference between (III-5) and the individual's initial income, Y,

$$D = I - Y = (P,H(A);\; \bar{U}) \tag{III-6}$$

Regional economic damages and the economic damage function can be operationally expressed as:

$$MBC_j = MB(A) \times PC_j + HS_j(A) \times HC_j + DU_j(A) \times DC_j \times POP_j \tag{III-7}$$

$$MBC = f(H(E,D,S,W,A;e),P) \tag{III-8}$$

where MBC_j denotes total morbidity cost in the jth urban area, MB is the morbidity rate, HS hospitalization rate, DU drug use rate, PC physician cost, HC hospitalization cost, DC drug cost, and POP is the population in the area. The notations in equation (III-8) were defined in Section II. That is,

1/ Equation 5 was labeled by Maler as the expenditure function. The analytical properties of such expenditure functions are delineated in K. G. Maler, Studies in Environmental Economics, in press.

E for the economic factors, D the demographic factors, S the social factors, W climatological factors, A air pollution, e error term, and P the commodity prices.

ADULT MORBIDITY AND AIR POLLUTION

Physical damage functions on adult morbidity are derived by the classical least-squares ‘linear regression technique and the random sampling, simulation technique. The few aggregated dose-response observations obtained from the CHESS study (1974) form the data base for the regression analysis in this study. The dose-response observation reported in the CHESS study related morbidity prevalence rate to particulates and sulfur dioxide in 1971 for four regions: Salt Lake Basin, Chicago, Rocky Mountain, and New York.1/

The CHESS communities in the Salt Lake Basin are located near the major copper smelter, and the local meteorological pattern provides an area gradient of exposure to sulfur oxides. The selected communities include Magna, Kearns Salt Lake City, and Ogden. Magna was designated the high exposure area because it had a high sulfur dioxide level due to its proximity to the smelter. Kearns, Salt Lake City, and Ogden were designated as Intermediate II, Intermediate I and Low exposure areas. These three cities had a descending exposure gradient to sulfur oxides.

The CHESS communities in the Chicago area include urban core, suburban areas and the relatively clean area, designated as High I, High II and Low pollution exposure areas for 1969-1970. The five communities selected in the Rocky Mountain area for the CHESS study are Anacenda, Kellogg, East Helena, Bozeman and.Helena, designated, respectively, as High I, High II, Low III, Low I and Low II exposure areas. For the New York City area, Riverhead, Long Island was chosen as a Low exposure community, the Howard Beach section of Queens as the Intermediate exposure community, and the Westchester section of the Bronx as a High exposure community.

The dose-response observations collected from the 15 CHESS communities in the four selected regions are summarized in Table III-I. The adjusted bronchitis prevalence rates expressed in percentages for the selected exposure areas are presented in Column 3 of the table. The annual average sulfur dioxide and total suspended particulates levels for the same set of communities are presented respectively in Column 4 and Column 5. It should be noted that the bronchitis prevalence rates presented in the CHESS report for Utah, Rocky Mountain and New York were adjusted for smoking status (e.g., nonsmoker, ex-smoker and smoker) and sex (e.g., mother and father), while the rates for Chicago were adjusted for education level, race and smoking status.

1/ For a general description about the EPA's CHESS Program, see Shy and Finkles (1973).

TABLE III-1. MORBIDITY DOSE - RESPONSE OBSERVATIONS

Area	Community	Adjusted Bronchitis Prevalence Rate (%)	Pollution Levels (ug/m^3)	
			SO_2 (1971)	TSP (1971)
Salt Lake Basin	Low	6.71	8	78
	Intermediate I	6.92	15	81
	Intermediate II	8.54	22	45
	High	10.77	62	66
Chicago	Low	25.97	19	71
	High I	25.30	96	155
	High II	21.22	217	103
Rocky Mountain	Low I	1.78	10	50
	Low II	5.10	26	45
	Low III	4.88	67	115
	High I	4.23	177	65
	High II	3.98	374	102
New York	Low	9.17	23	34
	Intermediate I	16.49	51	63
	Intermediate II	13.93	51	86

The adjusted bronchitis prevalence rates were regressed on the two pollutants to derive the dose-response functions for Salt Lake Basin, Chicago, Rocky Mountain and New York separately by the least-squares technique. The regression results are summarized in Table III-2. The regression fit between morbidity and SO_2 for New York, Chicago and Salt Lake Basin is fairly good, with R^2 having the values of 0.50, 0.88 and 0.94, respectively. Furthermore, SO_2 is significant at the 1 percent level for the New York and Salt Lake Basin regression equations. For total suspended particulates, good regression fit was obtained for Chicago and New York. However, TSP is consistently insignificant in expressing the variations in morbidity. These regression equations, coupled with the mean values and standard deviations of the pollutants and the morbidity prevalence rates presented in Table III-3, were used for a random sampling and simulation study to generate a "national" dose-response function which can be used for estimating morbidity damage costs in the various SMSA's.

ADULT MORBIDITY DAMAGES AND SULFUR DIOXIDE

Epidemiological studies have demonstrated that deterioration in air quality results in increased consumption of medical services and, hence, in economic loss to the pollution victims. To estimate such damage loss for the 40 SMSA's and to estimate an average economic damage function on adult morbidity, a random sampling technique for deriving a "representative" dose-response function was employed.

Random Sampling Simulation Study and the Physical Damage Function

"Simulation" is the technique of setting up a stochastic model of a real situation so that sampling experiments can be performed upon the model (Harling, 1958). Simulation study differs from the classical sampling experiment in that the former involves the construction of an abstract model, while the latter involves direct experiment with the new data. The term "simulation" is often used interchangeably with the term "Monte Carlo" technique.

The Monte Carlo technique, which was employed to generate the "average" nonlinear dose-response damage function vis-a-vis existing time series and cross-section studies, involves the study of probability models. As described by Dienemann (1966) the Monte Carlo technique can be defined as follows:

> Assume a system planner can describe each parameter with a probability distribution. This distribution is then treated as a theoretical population from which random samples are obtained. The method of taking such samples, as well as problems which rely on these sampling techniques, are often referred to as Monte Carlo methods.

TABLE III-2. ADULT MORBIDITY LINEAR DAMAGE FUNCTIONS

I. SO_2

(1) Rocky Mountain

$$MB\ (\%) = \underset{(0.94)^*}{3.84} + \underset{(0.005)}{0.001}\ SO_2 \qquad R^2 = 0.016$$

(2) Chicago

$$MB\ (\%) = \underset{(2.49)^*}{22.14} + \underset{(0.023)}{0.018}\ SO_2 \qquad R^2 = 0.50$$

(3) New York

$$MB\ (\%) = \underset{(3.46)}{4.2} + \underset{(0.08)^*}{0.21}\ SO_2 \qquad R^2 = 0.88$$

(4) Salt Lake Basin

$$MB\ (\%) = \underset{(0.46)^*}{6.22} + \underset{(0.013)^*}{0.075}\ SO_2 \qquad R^2 = 0.94$$

II. TSP

(1) Rocky Mountain

$$MB\ (\%) = \underset{(1.84)}{2.94} + \underset{(0.023)}{0.014}\ TSP \qquad R^2 = 0.109$$

(2) Chicago

$$MB\ (\%) = \underset{(3.52)^*}{18.42} + \underset{(0.03)}{0.05}\ TSP \qquad R^2 = 0.74$$

(3) New York

$$MB\ (\%) = \underset{(6.66)}{7.19.} + \underset{(0.10)}{0.098}\ TSP \qquad R^2 = 0.47$$

(4) Salt Lake Basin

$$MB\ (\%) = \underset{(4.90)^*}{11.97} - \underset{(0.07)}{0.05}\ TSP \qquad R^2 = 0.23$$

TABLE III-3. MEAN VALUES AND STANDARD DEVIATIONS OF THE VARIABLES

	Mean Value ($\bar{X}$)	Standard Deviation (S)
Utah		
Prevalence Rate	8.2	1.9
SO_2	26.8	24.2
TSP	67.5	16.3
Chicago		
Prevalence Rate	24.2	2.6
SO_2	110.6	99.8
TSP	109.6	42.4
Rocky Mountain		
Prevalence Rate	4.0	1.3
SO_2	132.8	150.8
TSP	75.4	31.4
New York		
Prevalence Rate	13.2	3.7
SO_2	41.2	16.2
TSP	61.0	26.1

A random sampling experiment was performed on the four sample regions in this study for deriving an "average" morbidity dose-response function. These four sample regions were constructed in the two dimensional space with the aid of the four regional dose-response functions shown in Part I of Table III-2, coupled with the data on the mean values and the standard deviations of the dependent and independent variable (see Table III-3). The four regional blocks are shown in Figure III-2, the vertical axis represents the morbidity rate expressed in number of incidences per 100 residents, and the horizontal axis denotes SO_2 pollutant concentrations level expressed in $\mu g/m^3$. For each sample block, the height of the block is the difference between the morbidity rate computed from the dose-response function with the coefficient of SO_2 in the function taking the value of (b + s) and (b - s), where b is the coefficient of SO_2 and s the associated standard error. The width of the block is, however, measured by the mean value of SO_2 plus and minus one standard deviation of the mean, i.e., $(\bar{X} + S)$ and $(\bar{X} - S)$ where $\bar{X}$ denotes the mean value of SO_2 and S the associated standard deviation.

Thus, the four sample blocks shown in Figure III-2 were defined on the basis of the four prior studies regarding the morbidity effect of SO_2 in the four different regions. The construction of these four blocks permits us to

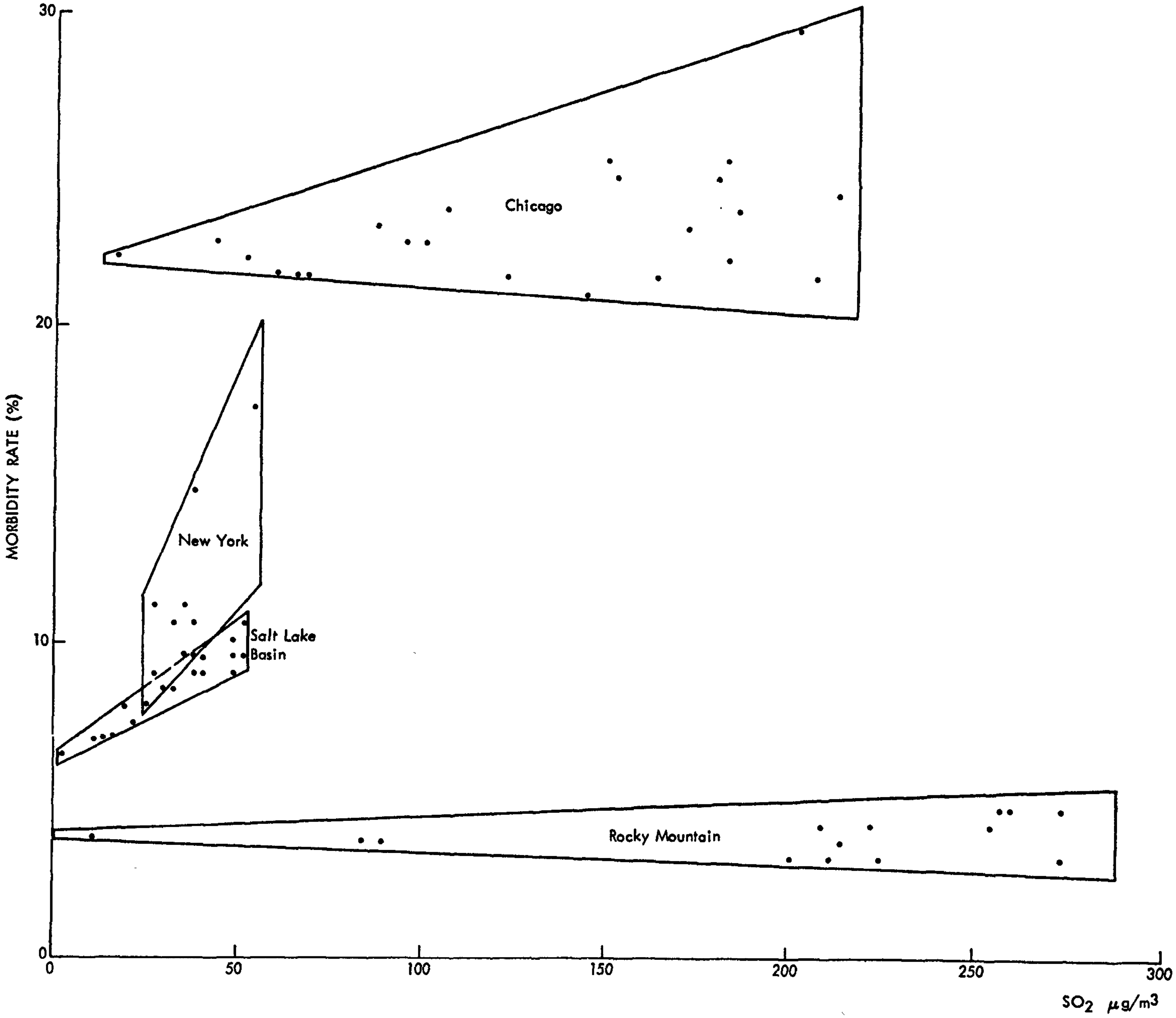

Figure III-1. Sample observation from four morbidity studies with respect to SO_2.

perform random sampling experiments. A random sample of 800 observations with 200 chosen from each block was obtained. To eliminate possible bias in the probability of being randomly selected resulting from the overlapping of the blocks, another random sampling was performed on the basis that two sorting schemes yield better results than one sorting procedure. A smaller sample of 81 observations, i.e., 10 percent of 800, was chosen. These 81 observations were used to develop a nonlinear "average" dose-response function specified alternatively as follows:

$$MB = C + EXP\ (a - b/SO_2) \qquad (III\text{-}9)$$

or

$$MB - C = EXP\ (a - b/SO_2)$$

$$(MB - C) = a - b/SO_2 \qquad (III\text{-}10)$$

As in the mortality study reported in Section II, the physical dose-response function in this morbidity study is again expressed as an exponential function which is consistent with *a priori* judgment and empirical results of medical experts regarding plausible human dose-responses to changes in pollution levels. The geometrical counterpart of this exponential relation is a long flat "S" curve, implying that while the air pollutant contributes to the morbidity incidence rate, the damaging effect is not proportional. In the presence of increased SO_2 level, the morbidity rate initially increases at an increasing rate and continues to increase, but at a decreasing rate after a certain inflection level.

Unlike the mortality study in which the intercept term C, conventional mortality, is expressed as a function of a number of socioeconomic, demographic and climatological variables, no such conventional morbidity function was estimated due to the lack of a systematic collection of morbidity data by the various SMSA's. Of necessity, the C term in equation (III-9) above is assumed to take the value of 11 since 11 is the arithmetic mean of the morbidity rates calculated from the four regional dose-response functions with the explanatory variable, SO_2 being at the threshold of 25 pg/m^3 for the sake of consistency with the earlier mortality study.

In estimating equation (III-9), the classical least-squares technique was applied. Since (MB - 11) may be negative, and the logarithm of a negative number is undefinable, (MB - 11) was therefore squared prior to its logarithm transformation. The resultant regression equation was then adjusted by dividing the coefficients by 2. A detailed discussion on the rationale of this procedure was presented in Section II.

The regression results for equation (III-9) look as follows:

$$MB = 11 + EXP(0.65 - 4.96/SO_2) \qquad \text{(III-11)}$$
$$(0.11)^* \quad (1.99)^*$$
$$R^2 = 0.072$$

The figures below the coefficients are standard errors, with * indicating that the coefficient of SO_2 is significant at the 1 percent level. However, the pollution variable SO_2 explains only about 7 percent of the variations in the residual morbidity rate, i.e., (MB - 11).

A linear morbidity equation was also fitted, with the regression result shown as follows:

$$MB = 12.06 - 0.01\ SO_2 \qquad \text{(III-12)}$$
$$(1.28)^* \quad (0.01)$$
$$R^2 = 0.011$$

Comparing the result of equation (III-11) to that of (III-12) the exponential dose-response function is apparently a better fit than the linear one because the former showed an explanatory power seven times larger than the latter equation. Furthermore, the coefficient of SO_2 in the exponential equation is statistically significant, whereas it is insignificant and has a wrong sign in the linear equation. Thus, the empirical results suggest that the nonlinearity in the dose-response relation is more consistent with a priori judgment regarding human health responses to pollution doses.

To recapitulate, the methodological procedures for estimating the dose-response function between morbidity rate and SO_2 are summarized as follows:

a. On the basis of the morbidity - SO_2 observations available for the four regions in the United States, a total of four regional morbidity dose-response functions with respect to SO_2 were derived via the classical least-squares regression technique.

b. Utilizing these four dose-response functions together with the information on the mean and standard deviations of the two variables, four blocks in the two-dimensional morbidity pollution space were constructed for random sampling experiments. A total of 800 random observations was taken in the first round experiment, among which a smaller size of 8 observations were again randomly selected for analytical purposes.

c. These 81 randomly selected observations were fitted to an exponential reciprocal equation to derive an "average" dose-response function for the four regions.

Like the mortality dose-response function, the nonlinear morbidity dose-response function has a number of distinguishing features: (1) the nonlinear dose-response function is not only more in accord with *a priori* judgment regarding human morbidity response to pollution doses, but also it is more amenable to being adjusted with whatever the assumed threshold level of SO_2 is in estimating the economic damages than the linear functions; and (2) for the purpose of predicting and estimating the marginal morbidity damages due to SO_2, the nonlinear equation has shown better fit and hence, will yield more accurate prediction over the linear one.

Economic Damages and Economic Damage Functions

Given the preceding nonlinear physical damage function, the economic costs of diseases related to air pollution can be estimated by transforming the additional morbidity rate into monetary units. Economic damages of morbidity, as discussed earlier, represent the amount that an individual or a society is willing to spend so as to maintain the previous preference level in the presence of the deterioration of air quality,.

Morbidity damages generally are comprised of two parts: direct and indirect costs of illness. Included in the direct costs of illnesses are the expenditures for prevention, detection, treatment, rehabilitation, research, training, and capital investment in medical facilities. Indirect costs of illness include the loss of output to the economy because of disability and the imputed costs such as opportunities foregone. A comprehensive framework for calculating the direct and indirect economic costs of illness and disability has been developed by Rice (1966) and others.

Both direct and indirect morbidity costs were estimated in the present study. Direct morbidity costs were computed by summing up the costs of physician visits, hospitalization costs, and drug costs. According to a recent study by Jaksch (1975), the average cost per physician visit for all ages combined in 1970 was $14, and the average cost of a hospital day for all ages combined was $82. To estimate total morbidity costs, further information is needed on the average number of physician visits and the average length of hospital stay per pollution-related disease incidence. A number of assumptions were made to obtain conservative morbidity damage estimates, as follows: (1) each pollution-related morbidity incidence results in one visit to consult a physician; (2) 1 of 8.3 physician visits, i.e., 12 percent, results in hospitalization; (3) drug costs run about 50 percent of the physician costs; (4) if hospitalization is required, each patient stays 1 day in the hospital for treatment.1/

1/ Various information on national data about the number of visits to doctors and the hospital days stayed per treatment can be obtained from Public Health Service (1973).

The conservative nature of both assumptions (1) and (4) leads to underestimations of the morbidity costs. The bias could be partially removed by assuming a greater number of physician visits and a longer hospital stay, however. The estimates presented in this study can be regarded as low estimates for morbidity costs. Assumption (2) is based on the calculated proportion of physician visits resulting in hospital discharge for four categories of diseases related to pollution (Jaksch, 1975). The figure 12 percent is the average of such proportions of physician visits in the four disease categories. Assumption (3) is, however, based on a ratio of total drug costs to total physician costs attributable to the use of oxidation catalyst as estimated by (Jaksch, 1975), i.e., 11.4/23.2 = 0.5.

The direct morbidity costs attributable to SO2 were estimated with the aid of the following formulas:

$$PCSO_2 = \$14 \times EXP\ [0.65 - 4.96/(SO_2 - 25)] \times POP \times NPV \qquad (III\text{-}13)$$

$$HCSO_2 = \$82 \times EXP\ [0.65 - 4.96/(SO_2 - 25)] \times 0.12 \times POP \times HSD \qquad (III\text{-}14)$$

$$DCSO_2 = 0.5 \times PCSO_2 \qquad (III\text{-}15)$$

where $PCSO_2$ = physician cost atttibutable to SO_2.

$HCSO_2$ = hospitalization cost attributable to SO_2.

$DCSO_2$ = drug cost attributable to SO_2.

POP = SMSA population.

NPV = number of physician visits per incidence = 1 (by assumption (1))

HSD = number of hospital stay days = 1 (by assumption (4))

Recall the physical dose-response function for SO_2 as expressed in equation (III-11) which has an intercept value of 11. If the exponential term in equations (III-13) and (III-14) is replaced by the value of the intercept of the dose-response function, then we can derive another set of cost estimates for morbidity in the absence of SO_2.

Another dimension of morbidity health costs is the indirect component regarding the changes in earnings and leisure opportunities because of disability and debility. A shortcut to estimate the indirect morbidity cost attributable to pollution was found by applying to the direct morbidity cost a multiplier of 2.4, which is the ratio of the best estimates of total indirect net costs and the total direct costs of morbidity (Jaksch, 1975). Hence, the following formula was used for estimating the indirect morbidity costs attributable to SO_2:

$$IMBCSO_2 = 2.4 \times (PCSO_2 + HCSO_2 + DCSO_2) \qquad \text{(III-16)}$$

The estimated morbidity costs for the 40 SMSA's with an SO_2 level equal to or greater than 25 $\mu g/m^3$, i.e., the threshold level, are presented in Table III-4. Columns 1, 2, and 3 present, respectively, the physician costs, hospital costs and drug costs attributable to SO_2. Indirect morbidity costs due to SO_2 are presented in Column 4. It should be noted that the figures in Column 4 are 2.4 times the sum of Columns 1, 2, and 3. Total morbidity costs due to SO_2 calculated by summing Columns 1, 2, 3 and 4 are presented in Column 5, and per capita total morbidity costs are in Column 6. Total morbidity costs in the absence of SO_2, direct and indirect, are presented in Column 7. The cost figures in this column were estimated with the aid of equations (III-13) to (III-16) with the modification of replacing the exponential term by the intercept term of the dose-response function. Finally, Column 8 presents the ratio of total morbidity cost attributable to SO_2 to total morbidity cost with and without SO_2, that is, Column 8 = Column 5/(Column 5 + Column 7). The extent of pollution damage to human health is partially reflected by the magnitude of this ratio.

Upon examination of the low estimates of morbidity costs in Table III-4, it is readily revealed that the annual morbidity costs due to SO_2 range from a minimum value of less than $1,000 in Cincinnati, Dayton, Evansville and Johnstown to a maximum of $22 million in New York City. Per capita morbidity costs attributable to SO in 1970 vary between cost of negligible magnitude to $1.96 in New York City. Total morbidity damages attributable to SO_2 over the 40 SMSA's were at least $99 million in 1970.

It should be stressed that the cost figures presented in the table represent <u>low</u> estimates for the morbidity damages due to the two conservative assumptions made for the calculation of the costs. If five instead of one is the average number of doctor visits, and the average number of days in the hospital is 5 days rather than 1 day per pollution-related disease incident, then by assuming the same costs incurred per visit to consult doctors and per hospital day for treatment, the cost figures in Columns 1 to 7 should be revised accordingly. In other words, the direct and indirect morbidity costs and the per capita total morbidity cost attributable to SO_2 should be five times as large as the low cost estimates calculated for the SMSA's.

An "average" economic damage function was derived for the purpose of predicting marginal and average changes in the morbidity costs in response to changes in the pollution or in other variables. The morbidity cost in the presence of SO_2, which is the sum of morbidity costs due to SO_2 and morbidity cost in the absence of pollution, was regressed on a host of socioeconomic, demographic and climatological variables. The stepwise regression results are shown as follows:

TABLE III-4. MORBIDITY COSTS WITH SO_2 BY SMSA's, 1970

SMSA	Direct Morbidity Costs Due to SO_2 (in $\$10^3$) PCSO2 (1)	HCSO2 (2)	DCSO2 (3)	Indirect Morbidity Costs Due to SO_2 (in $\$10^3$) IMBCSO2 (4)	Morbidity Cost Due to SO_2 Total (5) (in $\$10^3$)	Per Capita (6) ($)	Total Morbidity Cost Without SO_2 (in $\$10^3$) (7)	Ratio (8)=(5)÷((5)+(7)) (8)
1 AKR	151	106	75	796	1127	1.66	7834	0.13
2 ALL	125	88	62	660	935	1.72	6269	0.13
3 BAL	468	329	234	2474	3505	1.69	23883	0.13
4 BOS	323	227	162	1708	2420	0.88	31763	0.07
5 BRI	75	53	38	397	563	1.44	4500	0.11
6 CAN	37	26	19	196	277	0.74	4293	0.06
7 CHA	5	4	3	27	39	0.17	2647	0.01
8 CHI	1775	1248	888	9386	13200	1.91	80240	0.14
9 CIN	--	--	--	--	--	--	15973	--
10 CLE	487	343	244	2577	3651	1.77	23809	0.13
11 DAY	--	--	--	--	--	--	9807	--
12 DET	769	541	385	4066	5760	1.37	48280	0.11
13 EVA	--	--	--	--	--	--	2685	--
14 GAR	146	103	73	773	1095	1.73	7305	0.13
15 HAR	152	107	76	806	1142	1.72	7656	0.13
16 JER	148	104	74	782	1108	1.82	7027	0.14
17 JOH	---	--	--	--	--	--	3031	--
18 LAW	52	36	26	274	389	1.67	2681	0.13
19 LOS	1149	808	575	6075	8607	1.22	80920	0.10
20 MIN	332	233	166	1756	2487	1.37	20919	0.11
21 NHA	69	48	34	362	513	1.44	4120	0.11
22 NYO	3021	2123	1511	15900	22600	1.96	133280	0.14
23 NEW	329	231	165	1741	2467	1.33	21414	0.10
24 NOR	1280	900	640	7	10	0.01	7850	---
25 PAT	70	49	35	369	522	0.38	15673	0.03
26 PEO	643	452	322	3	5	0.01	3944	--
27 PHI	1188	835	594	6280	8897	1.85	55420	0.14
28 PTB	551	388	276	2916	4131	1.72	27696	0.13
29 POR	2	1	1	10	14	0.01	11639	--
30 PRO	218	153	109	1150	1629	1.78	10530	0.13
31 REA	29	21	15	156	221	0.74	3419	0.06
32 ROC	117	82	58	616	873	0.99	10181	0.08
33 STL	455	320	228	2407	3410	1.44	27255	0.11
34 SCR	23	16	12	123	174	0.74	2700	0.06
35 SPR	131	92	66	694	982	1.85	6112	0.14
36 TRE	40	28	20	212	301	0.99	3506	0.08
37 WAS	612	430	306	3238	4587	1.60	33001	0.12
38 WOR	40	28	20	214	303	0.88	3975	0.07
39 YOR	39	27	19	204	290	0.88	3801	0.07
40 YOU	53	37	27	282	399	0.74	6182	0.06
Total	15,104	10,617	7,558	69,637	98,633		783,202	

Note: -- denotes less than $1,000.

$$TMBCSO_2 = \underset{(80.3)}{52.4} + \underset{(0.09)^{*}}{0.60\ SO_2} - \underset{(67.9)^{*}}{135.0\ PWPO} + \underset{(0.7)^{**}}{1.4\ SUN} + \underset{(0.6)^{*}}{1.3\ RHM} -$$

$$\underset{(0.2)}{0.3\ DTS} + \underset{(0.10)}{0.09\ PCOL} + \underset{(310.4)}{34.4\ AGE} \qquad \text{(III-17)}$$

$$R^2 = 0.73$$

where $TMBCSO_2$ denotes the morbidity cost in the presence of SO_2, and all seven explanatory variables are the same as those defined previously in Section II. The values below the coefficients are standard errors, with * and ** to indicate that the coefficients are significant at the 1 and 5 percent level, respectively. All coefficients and the corresponding standard errors are reduced by a factor of 10^6. It should be pointed out that the primary use of equation (III-17) is only for prediction. "Wrong" signs as well as other statistical questions do not constitute a great problem if they are understood and accounted for.

In predicting and estimating the responsiveness of morbidity damages to changes in any one of the explanatory variables, the partial elasticity of the morbidity cost with respect to the variable of interest merits some discussion. Suppose a policymaker would like to estimate what the marginal changes will be in the morbidity cost if the pollution level of SO_2 in the SMSA's is lowered, on the average, by, say, 1 percent. In order to aid this policymaker to make the prediction, the partial elasticity of the morbidity cost with response to SO_2 (E_{MCB,SO_2}) is calculated as follows:

$$E_{MBC,SO_2} = 0.6 \times 10^6 \times (47.95/22.7 \times 10^6) = 1.27 \qquad \text{(III-18)}$$

where (0.6×10^6) is the coefficient of SO_2 in the economic damage function, and 47.95 and (22.7×10^6) are, respectively, the mean level of SO_2 and total morbidity cost.

In view of the SO_2 partial elasticity value of 1.27, the estimated morbidity cost would decrease by 1.27 percent, for every 1 percent reduction in SO_2 level, other things being equal. Stated differently, if the air pollution control program lowers the SO_2 level by 4.7 pg/m^3 from 47.9 to 43.2 $\mu g/m^3$ (10 percent reduction), adult morbidity costs on the average would decrease by $2.72 million, from $22.7 million to $19.98 million. In a like manner, the coefficients of other variables in equation (III-17) can be used to compute the partial elasticities associated with the variables and can be analogously interpreted as conditional marginal inpact when others are held constant.

ADULT MORBIDITY DAMAGES AND TOTAL SUSPENDED PARTICULATES

Total suspended particulates are directly harmful to human health. The poisonous substances or hydrocarbons contained in the particulates may cause cancer. Other particulates multiply the potential harm of irritant gases. For example, the interaction of sulfur dioxide gas with particulate matter will penetrate deep into the lungs and cause much greater harm. Some particulates expedite chemical reactions in the atmosphere to form harmful substances.

Arsenic, a well-known poison, may also cause cancer. Asbestos fiber is responsible for chronic lung disease. Beryllium has produced malignant tumors in monkeys. Cadmium, a respiratory poison, induces high blood pressure and heart disease. Lead, a cumulative poison, impairs the functioning of the nervous system in adults.

Adult morbidity.costs attributable to TSP were estimated by invoking the same methodology delineated above for deriving morbidity costs due to SO_2. The aggregate dose-response observations relating morbidity rate to TSP are presented in Table III-1, page 48. The observations, obtained from the report on the CRESS study, were used to estimate four separate regional, dose-response functions for the four study regions, i.e., Salt Lake Basin, Chicago, Rocky Mountain and New York. The regression results for the regional dose-response relations are shown in the lower half of Table III-2, page 50. The mean values and standard deviations of suspended particulates and the morbidity prevalence rates are presented in Table III-3, page 51.

The random sampling and simulation techniques delineated above were again applied to derive an "average" nonlinear dose-response function relating morbidity rates to suspended particulate levels. A total of 82 observations was randomly selected in the two-round sampling experiments from the four "blocks" defined in the two-dimensional morbidity and suspended particulate space as shown in Figure III-3. Given these 82 observations, least-squares regressions were run and the results are shown as follows:

$$MB = 11 + EXP\ (\underset{(0.22)^*}{1.75} - (\underset{(15.7)^*}{87.7}/TSP)) \qquad (III\text{-}19)$$

$$R^2 = 28$$

Again, the values below the coefficients are standard errors with * to indicate that the coefficients are significant at the 1 percent level. It should be noted that the intercept term 11 in equation (III-19) is the arithmetic mean of the morbidity rates calculated from the four regional dose-response functions with the dependent variable TSP being at the threshold level of 25 $\mu g/m^3$.

As in the case of SO_2, (MB - 11) was squared prior to its logarithmic transformation when the regression was run. The coefficients in equation (III-19)

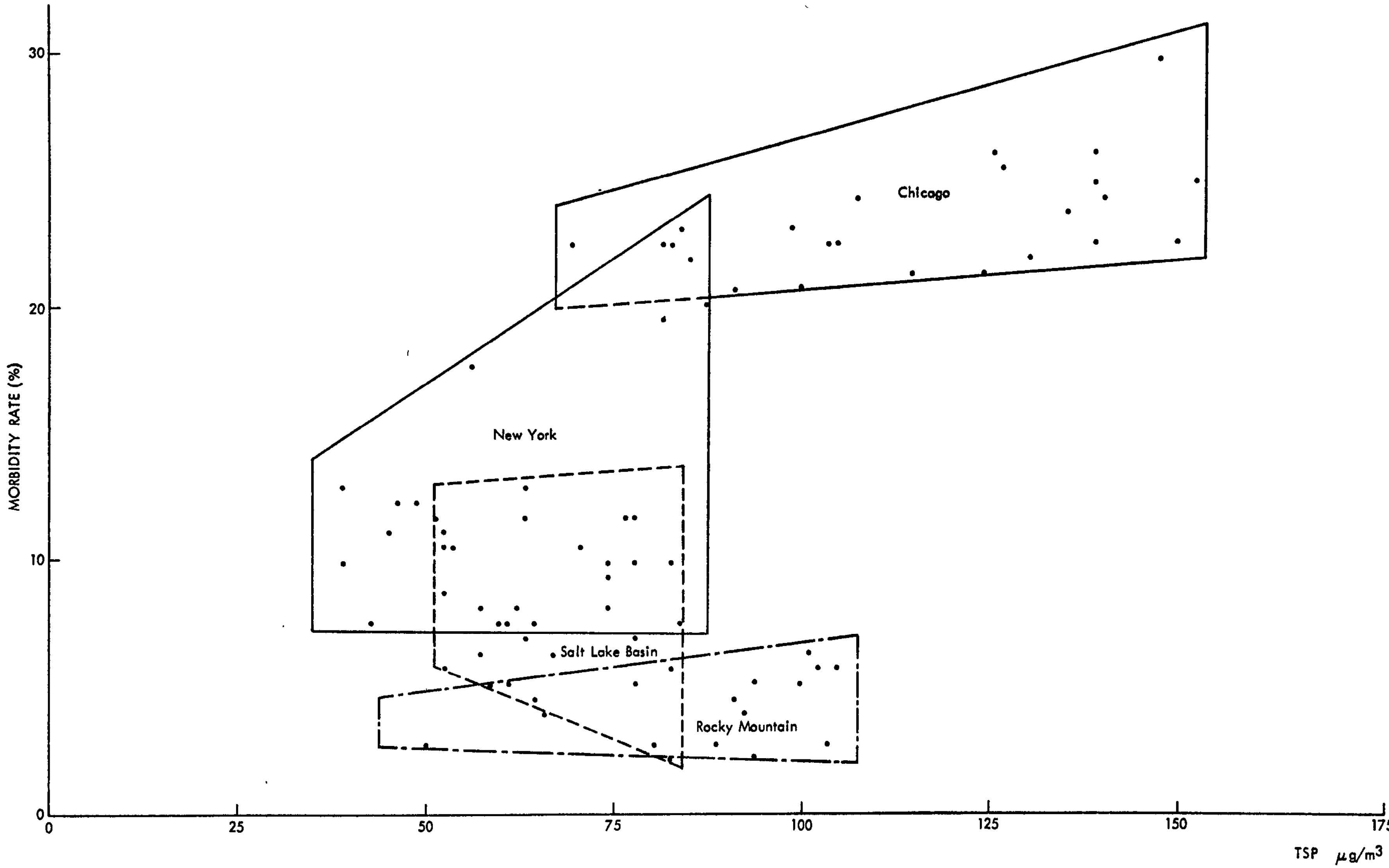

Figure III-2. Sample observations from four morbidity studies with respect to TSP.

were obtained by dividing also the regression coefficients log 2. The coefficient of TSP in this nonlinear dose-response function is also statistically significant at the 1 percent level and has a correct sign.

The direct morbidity costs attributable to TSP were estimated with the aid of the following formulas:

$$PCTSP = \$14 \times EXP\,[1.75 - 87.7/(TSP - 25)] \times POP \times NPV \qquad (III\text{-}20)$$

$$HCTSP = \$82 \times EXP\,[1.75 - 87.7/(TSP - 25] \times POP \times HSD \qquad (III\text{-}21)$$

$$DCTSP = 0.5 \times PCTSP \qquad (III\text{-}22)$$

where PCTSP = physician cost attributable to TSP.

HCTSP = hospitalization cost attributable to TSP.

DCTSP = drug costs attributable to TSP.

POP, NPV and HSD are the same as those defined in (III-13) and (III-14).

Applying the same multiplier of 2.4 used in the case of SO_2, the indirect morbidity costs due to TSP (IMBCTSP) were computed by

$$IMBCTSP = 2.4 \times (PCTSP + HCTSP + DCTSP) \qquad (III\text{-}23)$$

Morbidity costs for the 40 SMSA's with a TSP level equal to or greater than 25 $\mu g/m^3$ are tabulated in Table III-5. Physician costs, hospital costs, and drug costs attributable to TSP are presented in Columns 1 to 3, and indirect morbidity costs due to TSP in Column 4. Total and per capita morbidity costs attributable to TSP are presented in Columns 5 and 6. The ratio of total morbidity cost attributable to TSP to total morbidity cost associated with or without TSP is given in Column 8.

It should be again noted that the cost figures presented in this table, as those in the case of SO_2, are low estimates for the morbidity damage associated with TSP. If each pollution-related incidence results in, on the average, five rather than one visit to doctors, and the patients, if admitted to a hospital, will stay in the hospital for 5 days instead of 1 day, then, by assuming a constant cost for consuming medical services, the morbidity cost estimates in Columns 1 to 7 in Table III-5 will be magnified five times. Consequently, the total morbidity costs over the 40 SMSA's for each category (column) will also increase five times.

TABLE III-5. MORBIDITY COSTS WITH TSP BY SMSA's, 1970

SMSA	Direct Morbidity Cost Due to TSP (in $\$10^3$) PC TSP (1)	HC TSP (2)	DC TSP (3)	Indirect Morbidity Costs Due to TSP (in $\$10^3$) IMBCTSP (4)	Morbidity Cost Due to TSP Total (5) (in 10^3)	Per Capita (6) ($)	Total Morbidity Cost Without TSP (in $\$10^3$) (7)	Ratio (8)=(5)÷((5)+(7)) (8)
1 ARK	111	78	56	587	832	1.22	7834	0.10
2 ALL	106	75	53	563	797	1.47	6269	0.11
3 BAL	813	571	406	4298	6089	2.94	23883	0.20
4 BOS	771	542	386	4077	5776	2.10	31763	0.16
5 BRI	20	14	10	107	152	0.39	4500	0.15
6 CAN	97	68	49	515	730	1.96	4293	0.15
7 CHA	62	43	31	327	463	2.02	2647	0.15
8 CHI	2862	2012	1431	15100	21400	3.07	8240	0.21
9 CIN	378	266	189	1998	2830	2.04	15973	0.15
10 CLE	1010	710	505	5342	7567	3.67	23809	0.24
11 DAY	256	180	128	1352	1915	2.25	9807	0.16
12 DET	1705	1199	853	9016	12700	3.04	48280	0.21
13 EVA	32	23	16	172	243	1.04	2685	0.08
14 GAR	170	120	85	901	1277	2.02	7305	0.15
15 HAR	89	63	45	472	669	1.01	7656	0.08
16 JER	108	76	54	572	810	1.33	7027	0.10
17 JOH	69	48	34	364	515	1.96	3031	0.15
18 LAW	21	15	10	111	157	0.67	2681	0.06
19 LOS	2208	1552	1104	11600	16500	2.35	80920	0.17
20 MIN	262	184	131	1384	1960	1.08	20919	0.09
21 NHA	23	16	12	124	175	0.49	4102	0.04
22 NYO	2663	1872	1332	14000	19900	1.72	133280	0.13
23 NEW	669	470	334	3537	5011	2.70	21414	0.19
24 NOR	202	142	101	1070	1516	2.23	7850	0.16
25 PAT	65	45	32	342	484	0.36	15673	0.03
26 PEO	53	37	26	278	394	1.15	3944	0.09
27 PHI	742	521	371	3923	5557	1.15	55420	0.09
28 PTB	872	613	436	4608	6528	2.72	27696	0.19
29 POR	193	136	97	1021	1446	1.43	11639	0.11
30 PRO	136	96	68	720	1020	1.12	10530	0.09
31 REA	92	65	46	487	689	2.33	3419	0.17
32 ROC	184	130	92	975	1382	1.57	10181	0.12
33 STL	756	532	378	3998	5664	2.40	27255	0.17
34 SCR	110	78	55	584	828	3.53	2700	0.24
35 SPR	45	32	23	238	337	0.64	6112	0.05
36 TRE	36	26	18	192	253	0.90	3506	0.07
37 WAS	598	420	299	3162	4479	1.57	33001	0.12
38 WOR	43	30	21	227	322	0.93	3975	0.08
39 YOR	62	43	31	325	461	1.40	3801	0.11
40 YOU	154	108	77	814	1153	2.15	6182	0.16
Total	18,848	13,251	9,425	99,483	140,981		711,202	

The table reveals that the low estimate for morbidity damages attributable to TSP range from $0.15 million in Bridgeport to more than $21 million in Chicago. On a per capita basis, the low damage estimates for morbidity range from $360 in Paterson, New Jersey to $3,000 in Chicago. Total morbidity damages due to TSP over the 40 SMSA's were estimated to be at least $140 million in 1970.

Comparison of Tables III-4 and III-5 reveals that the morbidity costs associated with TSP are larger than the costs associated with SO_2. The total morbidity cost due to TSP is $141.2 million, while the total morbidity cost attributable to SO_2 is $98.4 million. The ratio between these two costs is 1.43. The larger morbidity cost due to TSP is attributable to the fact that the average TSP level (100.87 $\mu g/m$ is larger than the average SO_2 level (47.95 $\mu g/m$ and that TSP has a more responsive dose-response function than SO_2.

Note that an important assumption on the independency between SO_2 and TSP is made so that we can estimate the damage cost separately. In reality, the costs of SO_2 and TSP may be larger than the sum of the two component damages because of the possible interaction effects between the two pollutants.

However, another note of caution is warranted in interpreting the cost estimates presented in this study. The effect of SO_2 as indicated in the regression equation may represent the effect of not only the single pollutant SO_2 but also the effect of other pollutants, say TSP, as well. The prior pollution studies suggested that the variable SO_2 may serve as a proxy variable for air pollution. If this is the case, then the pollution damage estimates yielded by summing the two computed damages attributable to SO_2 and TSP may not necessarily be smaller than the actual pollution damages, even if the effect of interaction is accounted for. Whether the sum of the two component damages estimates is larger or smaller than the actual damages attributable to the concomitant presence of the two major pollutants depends on the balance of the magnitudes of the two opposing factors, i.e., the interaction effect versus the double counting effect.

An "average" economic damage function for TSP with respect to the 40 SMSA's was developed by the least-squares technique. Morbidity costs in the presence of TSP, i.e., the sum of the morbidity costs due to TSP, and the morbidity costs in the absence of pollution, were regressed against the same set of socioeconomic, demographic and climatological variables appearing earlier in the SO_2 economic damage function. The regression results are shown as follows:

$$\begin{aligned} TMBCTSP = & -43 + 0.55\,TSP - 131.7\,PWPO + 1.3\,SUN + 1.2\,RHM \\ & \;(74)\quad (0.09)^{*} \qquad (63.3)^{*} \qquad (0.7)^{**} \qquad (0.6)^{*} \\ & - 0.2\,DTS + 0.07\,PCOL + 35.0\,AGE \\ & \quad (0.2) \qquad (0.09) \qquad (289.7) \end{aligned} \qquad (III\text{-}24)$$

$$R^2 = 0.72$$

where TMBCTSP denotes the total morbidity cost in the presence of TSP, and all seven explanatory variables are identical to those defined previously in Section II. The values below the coefficients are standard errors, with * and ** to denote that the coefficients are significant at the 1 and 5 percent levels. All coefficients and the corresponding standard errors are reduced by a factor of 10^6.

Since equation (III-24) is developed mainly for prediction purposes, the "unexpected" signs and possible colinearity among the independent variables should not present a problem to the use of this equation for estimating TMBCTSP provided that the signs and the multicolinearity will persist in the future. However, the use of partial elasticity between the dependent and the independent variable with wrong signs does cause difficulty in interpreting the results.

This average economic damage function again is useful for forecasting and estimating the changes in adult morbidity costs in response to changes in any of the climatological, demographic, and socioeconomic characteristics, and the suspended particulate variable. The partial elasticity of the morbidity damages with respect to suspended particulates is computed as follows: $E_{MCB,TSP} = 0.55 \times (100.87/708) = 0.08$, as measured from the respective mean levels of total morbidity costs and suspended particulates. Thus, if the suspended particulate level in the air is lowered by 10.1 $\mu g/m^3$ from 100.87 to 90.76 $\mu g/m^3$ (i.e., 10 percent reduction), gross adult morbidity costs on the average would reduce by $5.66 million from $708 to $702.3 million nationwide.

SECTION IV

HOUSEHOLD SOILING AND AIR POLLUTION

THE PROBLEMS AND THE OBJECTIVES

In addition to human health, air pollution has also a multitude of damaging effects on material, vegetation, animals, and residential and commercial establishments, etc. Ronald Ridker (1967) designed a framework for identifying and quantifying these damage costs. He suggested that the effects of air pollution and their costs can be categorized into: (1) cost of direct effects, (2) adjustment costs, and (3) market effect costs. The damage costs of human health derived in the previous two chapters are costs of direct effects of air pollution. The present section is concerned with the second category; i.e., adjustment costs or the cost of individual adjustments to the effects of air pollution.

The best known and the pioneering contribution to the estimation of soiling loss due to air pollution is the Mellon Institute Study of the Pittsburgh smoke nuisance (1913). The $20.00 per capita soiling cost figure of the Mellon Institute Study has been used as a basis for extrapolating to the $11 billion national damage estimate. The validity of this damage estimate, often quoted by public officials, has been questioned by Jones (1969) and others. A serious problem with the national damage estimate arises because of the strong assumption that the air pollution level in Pittsburgh is representative of the entire nation.

The two studies of quantifying the soiling costs in the Upper Ohio River Valley and Washington, D. C. carried out by Michelson and Tourin (1966) have also attracted public attention. Their methodology is based on the hypothesis that significant soiling due to air pollution may be reflected in shortened time intervals between successive cleaning and maintenance operations. Michelson and Tourin established a positive relationship between frequency of cleaning operations and the levels of air pollution in both studies. However, the problems with the sample survey design and the lack of a statistically reliable technique cast doubt on the reliability of their findings. Michelson and Tourin (1968) employed the same methodology and estimated the extra household soiling costs due to air pollution in Connecticut. They found that an average household spent about $600 each year for coping with the effect of suspended particulates, with the range from $230 per year in Fairfield to $725 per year in Bridgeport. These cost estimates are conservative since the cleaning operations studied did not cover the full gamut of operations affected by air pollution.

Ridker (1967) conducted interurban studies to determine the relation between per capita soiling costs and air pollution level for 144 cities in the United States. Soiling damage costs were approximated by per capita expenditures on laundry and dry cleaning services. Ridker found that no discernible patterns between soiling costs and the suspended particulate levels were detected, whether the effects of climate, per capita income, and price differentials were controlled for or not. The problem often encountered in identifying the soiling damages, as noted by Ridker, is that cleaning and maintenance operations are often undertaken on a rigid schedule which is independent of the location of the operation. This is especially true for commercial and industrial buildings. Furthermore, nonpollution factors which could not be controlled for may be important in explaining the cleaning and maintenance procedures.

The primary objectives of this study are threefold: a system of soiling physical damges functions which relate various types of cleaning frequencies to air pollution level are derived. The physical damage functions are then utilized to estimate net and gross soiling damage costs for the 148 SMSA's. Finally, "average" economic damage functions over the United States metropolitan areas are developed by relating soiling damages to air pollution, demographic, socioeconomic, and climatological variables. It is hoped that the generalized economic damage functions presented in this section are informative and useful for predicting possible benefits as a result of the reduction in air pollution when air pollution abatement programs are implemented.

This section,which represents a first exploratory effort to estimate average air pollution soiling damage functions and soiling damage costs for the 148 SMSA's individually, contains subsections: Soiling Physical Damage Function, and Economic Damages and Economic Damage Functions.

SOILING PHYSICAL DAMAGE FUNCTIONS

Soiling as a result of falling total suspended particulates compels households as well as business and industrial establishments to increase cleaning activities. Thus, soiling has resulted in extra economic losses not only to households but to business and industrial firms as well. As noted above, a number of attempts have been undertaken to identify and quantify the soiling damages due to air pollution. However, a recent study by Booz, Allen and Hamilton, Inc. (1970), offers the needed data base for our purpose of developing the soiling physical damage functions.

Sophisticated and rigorous statistical survey techniques were employed by Booz-Allen researchers. The Renjerdel area around Philadelphia, Pennsylvania, was used as the data gathering area. Frequency of cleaning by the residents was determined by a carefully developed questionnaire containing queries regarding cleaning operations and a set of self-referent statements with respect to cleaning attitudes. Among the 27 cleaning and maintenance operations, the study shows that 11 were somewhat. sensitive to air-suspended particulate levels. Because of the lack of certain needed information for evaluating the costs, only 9 of these 11 cleaning tasks were considered in this study. A list of these nine pollution-related cleaning tasks together with the information on unit cleaning costs is contained in Table IV-1.

TABLE IV-1. POLLUTION-RELATED TASKS AND THEIR UNIT CLEANING COSTS

Tasks		Unit Market Value ($)
1	Replace air conditioner filter	1.00
2	Wash floor surface	6.00
3	Wash inside window	0.50
4	Clean Venetian blinds/shades	3.50
5	Clean/repair screens	0.20
6	Wash outside windows	1.50
7	Clean/repair storm windows	2.00
8	Clean outdoor furniture	10.00
9	Clean gutters	15.00

A set of physical damage functions was derived via the technique delineated in Section III above, which combines the simulation and regression analysis. The areas under study were divided into four zones according to their air pollution levels. This breakdown in the study areas allows one to construct four population "blocks" for each pollution-related cleaning task in the two-dimensional pollution level and cleaning frequency spaces. For ease of description, let X and Y denote respectively the suspended particulate level and cleaning frequency. The vertices of each "block" then consist of the following four combinations: [Max X, Max Y]; [Max X, Min Y]; [Min X, Max Y]; and [Min X, Min Y], where Max and Min denote the upper and lower limits of the two variables. The annual average particulate levels ($\mu g/m^3$) in the four sampling zones were given in the Booz-Allen report as follows:

Zone 1	$X < 75$
Zone 2	$75 < X < 100$
Zone 3	$100 < X < 125$
Zone 4	$125 < X$

Thus, the suspended particulate levels, X, vary from 75 $\mu g/m^3$ to 100 $\mu g/m^3$ in Zone 2 and from 100 $\mu g/m^3$ to 125 $\mu g/m^3$ in Zone 3. The upper limit of X in Zone 1 is 75 $\mu g/m^3$ and the lower limit of X in Zone 4 is 125 $\mu g/m^3$. Assuming that 25 $\mu g/m^3$ of suspended particulate is the background concentration level and 175 $\mu g/m^3$ is the upper limit in the study areas then the values of Min X and Max X (in $\mu g/m^3$) for the four study zones are tabulated as follows:

	Min X	Max X
Zone 1	25	75
Zone 2	75	100
Zone 3	100	125
Zone 4	125	175

The minimum and the maximum values for the dependent variable Y (Min Y and Max Y) for each zone were calculated by subtracting and adding one standard error of the mean from the mean value of the cleaning frequency. The computed values for Min Y and Max Y, the mean frequency of cleaning and the standard error of the means are presented in Table IV-2.

The Monte Carlo sampling technique, delineated in Section III, was applied to the four blocks for generating a random sample for the regression analysis. A total of 800 such random observations for each cleaning task were selected. For the sake of computational simplicity, a smaller random sample, about 20 percent of the 800 random observations, was further obtained. The 160 observations included in this sample were fitted via both linear and nonlinear least-squares techniques. The linear fit is more superior than the nonlinear fit in all cases except for Task 8. The linear regression results for Task 1 through 7 and Task 9 and the nonlinear regression result for Task 8 are summarized in Table IV-3.

ECONOMIC DAMAGES AND ECONOMIC DAMAGE FUNCTIONS

Given the preceding nine physical damage functions for the nine pollution-related cleaning tasks and the associated unit cleaning costs which were obtained through telephone conversations with various cleaning firms in Kansas City, the economic costs of soiling or of individual household adjustment to air pollution can be derived by transforming the increased cleaning frequency into monetary units, via the following two formulas:1/

1/ For Task 8, NSCO8 = EXP (0.85 - 0.015/(TSP - 45)) . UC . U . HU and GSC08 = 2 + EXP (0.85 - 0.015/(TSP - 45)) . UC . U . HU.

TABLE IV-2. MEAN FREQUENCY, STANDARD ERROR AND UPPER AND LOWER LIMITS OF FREQUENCY AND SUSPENDED PARTICULATES

		Mean Frequency of Cleaning	Standard Error of Means	Min Y	Max Y	Min X	Max X
Task 1							
	Zone 1	0.36	0.06	0.30	0.42	25	75
	Zone 2	0.50	0.08	0.42	0.58	75	100
	Zone 3	0.30	0.07	0.23	0.37	100	125
	Zone 4	0.98	0.34	0.64	1.32	125	175
Task 2							
	Zone 1	40.55	0.84	39.71	41.39	25	75
	Zone 2	42.06	0.84	41.22	42.90	75	100
	Zone 3	42.74	0.98	41.77	43.72	100	125
	Zone 4	45.17	0.93	44.24	46.10	125	175
Task 3							
	Zone 1	10.06	0.61	9.45	10.17	25	75
	Zone 2	11.78	0.70	11.08	12.48	75	100
	Zone 3	12.74	0.82	11.93	13.55	100	125
	Zone 4	18.45	1.10	17.85	20.05	125	175
Task 4							
	Zone 1	4.04	0.53	3.51	4.57	25	75
	Zone 2	6.17	0.66	5.51	6.87	75	100
	Zone 3	9.13	0.91	8.22	10.04	100	125
	Zone 4	9.21	0.49	8.22	10.20	125	175
Task 5							
	Zone 1	0.80	0.07	0.75	0.87	25	75
	Zone 2	0.93	0.16	0.77	1.09	75	100
	Zone 3	0.79	0.10	0.70	0.86	100	125
	Zone 4	1.50	0.32	1.18	1.82	125	175
Task 6							
	zone 1	4.25	0.35	3.90	4.60	25	75
	Zone 2	4.59	0.38	4.21	4.97	75	100
	Zone 3	6.17	0.60	5.57	6.77	100	125
	Zone 4	10.09	0.88	9.21	10.97	125	175
Task 7							
	Zone 1	2.07	0.28	1.79	2.35	25	75
	Zone 2	1.60	0.23	1.37	1.83	75	100
	Zone 3	2.12	0.39	1.73	2.51	100	125
	Zone 4	3.69	0.63	3.60	4.32	125	175
Task 8							
	Zone 1	2.50	0.45	2.05	2.95	25	75
	Zone 2	4.29	0.65	3.64	4.94	75	100
	Zone 3	3.52	0.71	2.81	4.23	100	125
	Zone 4	1.19	0.47	0.72	1.66	125	175
Task 9							
	Zone 1	1.12	0.22	0.91	1.34	25	75
	Zone 2	1.54	0.33	1.21	1.87	75	100
	Zone 3	1.35	0.44	0.91	1.79	100	125
	Zone 4	2.80	0.69	2.11	3.49	125	175

TABLE IV-3. SOILING PHYSICAL DAMAGE FUNCTIONS[a/]

A. Frequency = a + b TSP

Task	a	b	R^2
1	0.03	0.00510	0.43
	(0.05)	(0.00048)*	
2	38.6	0.0400	0.80
	(0.18)	(0.0017)*	
3	5.6	0.078	0.76
	(0.4)	(0.036)*	
4	2.3	0.048	0.79
	(0.2)	(0.002)*	
5	0.42	0.0059	0.48
	(0.06)	(0.0049)*	
6	1.00	0.0530	0.74
	(0.28)	(0.0025)*	
7	0.85	0.015	0.48
	(0.15)	(0.001)*	
9	0.27	0.0140	0.55
	(0.12)	(0.0011)*	
B. Frequency = $c + e^{(a-b/TSP)}$			
8	0.67	53.2	0.26
(c = 2)	(0.10)	(7.4)*	

a/ The values below the coefficients are standard errors, with * to indicate that the coefficient is significant at the 1 percent level.

$$NSCO_i = b_i(TSP-45) \cdot UC \cdot U \cdot HU \qquad (IV\text{-}1)$$

$$GSCO_i = a_i + b_i(TSP-45) \cdot UC \cdot U \cdot HU \qquad (IV\text{-}2)$$

where NSCOi, and $GSCO_.$ are, respectively, the net (extra) and gross soiling damage cost for the ith type of cleaning task. Coefficients a_i and b_i are the estimated coefficients in the physical damage functions in Table IV-3. i = 1 through 7, and 9. Variables UC, U and HU stand for the unit market value, number of cleaning objects per household and number of households in a metropolitan area, respectively.

To capture the "real" effect of suspended particulates on soiling damages, the suspended particulate level was adjusted by a threshold level because a low level of suspended particulate might have a negligible effect on the household cleaning activities. A threshold level of 45 $\mu g/m^3$ for suspended particulate was assumed as the background concentration level in this study because the lowest 1970 annual mean level for total suspended particulates was 46.7 $\mu g/m^3$ for Charleston, South Carolina. Alternative reasonable threshold levels can also be considered. Other things being equal, a higher threshold level is generally associated with a lower damage cost, and the marginal changes in the damage cost in response to a unit change in the threshold level is the value of b_i for the ith type of cleaning task.

Given the data collected for the variables in the formula (IV-1) and (IV-2) the net and gross household soiling costs for each of the nine cleaning operations by the 65 large SMSA's (with population greater than 500,000) in the United States were derived and presented in Tables IV-4 and IV-6. Similar damage costs for each of the nine cleaning operations by the 83 medium SMSA's (200,000 to 500,000 people) were presented in Tables IV-6 and IV-7. An examination of the table reveals that Chicago, New York, and Los Angeles, in order of magnitude, suffered the most in terms of total net soiling damages. The net soiling damages in these three SMSA's in 1970 are, respectively, $516 million, $418 million, and $388 million. It is noteworthy that the cleaning activities of Tasks 4 and 6 in response to air pollution had resulted in an economic damage of about $1,956 million and $925.7 million, respectively, in the 40 metropolitan areas. These two tasks constitute the largest damage categories among the nine pollution-related cleaning tasks.

Per capita net and gross soiling damage costs in the presence of air pollution for large SMSA's and medium SMSA's for 1970 are presented, respectively, in Tables IV-8 and IV-9. Per capita net soiling costs (PCNSCO) and per capita gross soiling costs (PCGSCO) are summarized in the second and the third columns of the tables. These cost figures indicate that the soiling damages attributable to air pollution in large SMSA's range from $5 per person in San Antonio, Texas, to $104 per person in Cleveland, Ohio, whereas the net soiling damages in medium SMSA's vary from less than a dollar per person in Charleston, South Carolina, to $67.35 per person in Wichita, Kansas. These estimates for individual SMSA's appear to be compatible with the overall per capita soiling damage estimates of $20.00 by Mellon Institute and of $200 by Michelson and Tourin.

TABLE IV-4. NET SOILING DAMAGE COSTS BY LARGE SMSA's[a]
(million $)

Large SMSA's	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
1. AKR, OH	--	1.7	1.4	6.3	--	2.9	1.1	0.9	1.5	15.5
2. ALB, NY	0.1	4.0	3.2	14.0	0.1	6.7	2.5	2.2	3.5	36.4
3. ALL, NJ	--	1.8	1.4	6.2	--	2.9	1.1	1.0	1.5	15.9
4. ANA, CA	0.1	6.1	5.0	21.3	0.2	10.1	3.8	3.4	5.3	55.4
5. ATL, GA	0.1	3.8	3.1	13.1	0.1	6.2	2.4	2.0	2.2	34.0
6. BAL, MD	0.3	15.3	12.4	53.6	0.4	25.3	9.6	7.3	13.4	137.0
7. BIR, AL	0.2	7.7	6.2	26.7	0.2	12.6	4.7	3.1	6.7	68.2
8. BOS, MA	0.3	12.9	10.5	45.3	0.3	21.4	8.1	7.2	11.3	117.0
9. BUF, NY	0.2	8.1	6.6	28.3	0.2	12.4	5.1	4.2	7.1	73.1
10. CHI, IL	1.2	57.5	46.7	201.0	1.4	95.2	35.9	26.2	50.3	516.0
11. CIN, OH-KY-IN	0.1	6.3	5.1	21.9	0.2	10.4	3.9	3.5	5.5	57.0
12. CLE, OH	0.5	24.3	19.7	85.0	0.6	40.2	15.1	9.0	21.2	216.0
13. COL, OH	0.1	2.3	1.9	8.2	0.1	3.9	1.5	1.2	2.1	21.1
14. DAL, TX	0.1	6.8	5.5	23.7	0.2	11.2	4.2	3.8	5.9	61.4
15. DAY, OH	0.1	4.4	3.5	15.2	0.1	7.2	2.7	2.4	3.8	39.4
16. DEN, CO	0.2	10.1	8.2	35.3	0.2	16.7	6.3	4.7	8.8	90.7
17. DET, MI	0.7	32.7	26.6	114.0	0.8	54.3	20.4	15.1	28.6	294.0
18. FOR, FL	--	0.9	0.7	3.2	--	1.5	0.6	0.2	0.8	7.8
19. FOR, TX	0.1	2.6	2.1	9.2	0.1	4.3	1.6	1.5	2.3	23.7
20. GAR, IN	0.1	2.7	2.2	9.3	0.1	4.4	1.7	1.5	2.3	24.2
21. GRA, MI	--	1.1	0.9	4.0	--	1.9	0.7	0.5	1.0	10.1
22. GRE, NC	--	1.9	1.5	6.5	--	3.1	1.2	1.0	1.6	16.9
23. HAR, CT	--	1.8	1.4	6.2	--	2.9	1.1	0.8	1.6	15.8
24. HON, HI	--	1.2	1.0	4.1	--	2.0	0.7	0.5	1.0	10.5
25. HOU, TX	0.1	6.4	5.2	22.4	0.2	10.6	4.0	3.5	5.6	58.1
26. IND, IN	0.1	2.5	2.0	8.9	0.1	4.2	1.6	1.2	2.2	22.7
27. JAC, FL	--	1.2	0.9	3.8	--	1.8	0.7	4.7	0.9	9.7
28. JER, NJ	--	1.9	1.5	6.7	--	3.2	1.2	1.0	1.7	17.2
29. KAN, MO-KS	0.1	4.0	3.3	14.1	0.1	6.7	2.5	2.2	3.5	36.6
30. LOS, CA	0.9	42.8	34.8	150.0	1.1	71.0	2.7	2.3	3.8	388.0
31. LOU, KY-IN	0.1	6.3	5.1	21.9	0.2	0.2	10.3	3.9	5.5	56.3
32. MEM, TN-AR	0.1	2.6	2.1	9.2	0.1	4.4	1.6	1.5	2.3	23.8
33. MIA, FL	--	1.7	1.4	6.0	--	2.9	1.1	0.3	1.5	15.0
34. MIL, WI	0.1	4.8	3.9	16.9	0.1	8.0	3.0	2.7	4.2	43.9
35. MINN, MN	0.1	4.1	3.3	14.4	0.1	6.8	2.6	1.9	3.6	36.9

a/ NSCOi stands for the net soiling cost for the ith type of operation, i = 1, 2,. . . ., 9.
TOTNETSL is the sum of NESOCOi over i and "--" indicates that the figure is less than 0.05.

TABLE IV-4 (Concluded)

Large SMSA's	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
36. NAS, TN	0.1	3.2	2.6	11.1	0.1	5.3	2.0	1.7	2.8	28.9
37. NEW, LA	0.1	2.7	2.2	9.3	0.1	4.4	1.7	1.3	2.3	23.9
38. NEW, NY	1.0	46.0	37.4	161.0	1.1	76.3	28.7	25.8	40.3	418.0
39. NEW, NJ	0.3	12.4	10.1	43.5	0.3	20.6	7.8	6.3	10.8	112.0
40. NOR, VA	0.1	3.2	0.6	11.0	0.1	5.2	2.0	1.7	2.8	28.5
41. OKL, OK	--	1.2	0.9	3.8	--	1.8	6.8	0.3	1.0	9.6
42. OMA, NE-LA	0.1	3.8	3.1	13.2	0.1	6.3	2.4	1.8	3.3	34.0
43. PAT, NJ	--	1.1	0.9	3.8	--	1.8	0.7	0.1	1.0	9.3
44. PHI, PA-NJ	0.2	11.5	9.4	40.4	0.3	19.1	7.2	5.6	10.1	104.0
45. PHO, AZ	0.2	10.4	8.5	36.4	0.3	17.2	6.5	4.1	9.1	92.8
46. PIT, PA	0.3	16.3	13.2	57.1	0.4	27.0	10.2	8.2	14.2	147.0
47. POR, OR-WA	0.1	3.3	2.7	11.6	0.1	5.5	2.1	1.8	3.0	30.1
48. PRO, RI-MA	--	2.2	1.8	7.7	0.1	3.6	1.4	1.1	1.9	19.7
49. RIC, VA	0.1	2.7	2.2	9.4	0.1	4.4	1.7	1.5	2.3	24.2
50. ROC, NY	0.1	3.1	2.4	10.2	0.1	4.9	1.8	1.6	2.5	26.5
51. SAC, CA	--	1.0	0.8	3.5	--	1.7	0.6	0.2	0.9	8.8
52. SAI, MO-IL	0.3	13.1	10.6	46.0	0.2	21.7	8.2	7.0	11.5	119.0
53. SAL, UT	--	1.9	1.5	6.6	--	3.1	1.2	1.2	1.7	17.2
54. SAN, TX	--	0.5	0.4	1.8	--	0.8	0.3	--	0.4	4.3
55. SAN, CA	0.1	7.9	6.3	27.5	0.2	13.0	4.9	3.9	6.9	70.8
56. SAN, CA	--	1.4	1.1	4.8	--	2.3	0.9	0.2	1.2	11.9
57. SAN, CA	0.1	4.0	3.2	14.0	0.1	6.7	2.5	0.6	3.5	34.8
58. SAN, CA	--	1.2	0.9	4.0	--	1.9	0.7	0.2	1.0	10.0
59. SEA, WA	--	1.4	1.2	5.0	--	2.3	0.9	0.1	1.2	12.1
60. SPR, MC-CT	--	0.8	0.6	2.7	--	1.3	0.5	0.2	0.7	6.7
61. SYR, NY	0.1	3.0	2.5	10.6	0.1	5.0	1.9	1.7	2.7	27.4
62. TAM, FL	0.1	2.7	2.2	9.4	0.1	4.5	1.7	1.3	2.4	24.2
63. TOL, OH-MI	0.1	4.0	3.3	14.1	0.1	6.7	2.5	2.1	3.5	36.4
64. WAS, DC-MD-VA	0.2	9.7	7.8	37.7	0.2	15.9	6.0	5.42	8.4	85.5
65. YOU, OH	0.1	2.5	2.0	8.9	0.1	4.2	1.6	1.4	2.2	23.0
Total	9.9	474.5	382.7	1,662.0	10.6	774.0	284.7	216.8	379.7	2,465.9

TABLE IV-5. NET SOILING DAMAGE COSTS BY MEDIUM SMSA's
(million $)

Medium SMSA's	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
66. ALB, NM	--	1.1	0.9	3.7	--	1.8	0.7	0.6	0.9	9.7
67. ANN, MI	--	0.5	0.4	1.7	--	0.8	0.3	0.2	0.4	4.3
68. APP, WI	--	0.9	0.7	3.1	--	1.4	0.5	0.5	0.8	7.9
69. AUG, GA-SC	--	0.3	0.3	1.1	--	0.5	0.2	0.1	0.3	2.7
70. AUS, TX	--	0.5	0.4	1.9	--	0.9	0.3	0.2	0.5	4.8
71. BAK, CA	--	2.2	1.8	7.7	0.1	3.7	1.4	1.1	1.9	19.9
72. BAT, LA	--	0.3	0.3	1.1	--	0.5	0.2	0.1	0.3	2.7
73. BEA, TX	--	0.3	0.3	1.2	--	0.6	0.2	0.1	0.3	3.0
74. BIN, NY-PA	--	0.3	0.2	1.0	--	0.4	0.2	--	0.2	2.5
75. BRI, CN	--	0.4	0.3	1.2	--	0.6	0.2	--	0.3	3.0
76. CAN, OH	--	1.6	1.3	5.6	--	2.6	1.0	0.9	1.4	14.4
77. CHA, SC	--	--	--	0.1	--	0.1	--	--	--	0.3
78. CHA, WV	--	1.1	0.9	3.7	--	1.8	0.7	0.6	0.9	9.6
79. CHA, NC	--	1.6	1.3	5.7	--	2.7	1.0	0.9	1.4	14.6
80. CHA, TN-GA	--	1.4	1.2	5.0	--	2.4	0.9	0.8	1.2	12.9
81. COL, CO	--	0.8	0.7	2.9	--	1.4	0.5	0.5	0.7	7.6
82. COL, SC	--	0.4	0.4	1.3	--	0.6	0.2	0.1	0.3	3.2
83. COL, GA-AL	--	0.1	0.1	0.3	--	0.1	--	--	0.1	0.7
84. COR, TX	--	1.1	0.9	4.0	--	1.9	0.7	0.6	1.0	10.2
85. DAV, IA-IL	--	2.3	1.8	8.0	0.1	3.8	1.4	1.1	2.0	20.4
86. DES, IA	--	0.9	0.7	3.1	--	1.5	0.6	0.5	0.8	8.1
87. DUL, MN-WI	--	0.5	0.4	1.9	--	0.9	0.3	0.2	0.5	4.8
88. ELP, TX	--	2.2	1.9	7.9	--	3.8	1.4	1.1	2.0	20.1
89. ERI, PA	--	1.1	0.9	3.9	--	1.9	0.7	0.6	1.0	10.0
90. EUG, OR	--	0.7	0.5	2.3	--	1.1	0.4	0.4	0.6	6.0
91. EVA, IN-KY	--	0.5	0.4	2.0	--	0.9	0.3	0.3	0.5	5.0
92. FAY, NC	--	0.3	0.2	0.9	--	0.4	0.2	0.1	0.2	2.2
93. FLI, MI	0.1	3.0	2.4	10.2	0.1	4.9	1.8	1.5	2.6	26.5
94. FOR, IN	--	0.6	0.5	2.2	00	1.0	0.4	0.3	0.5	5.6
95. FRE, CA	--	2.1	1.7	7.5	0.1	3.5	1.3	1.2	1.9	19.3
96. GRE, SC	--	0.7	0.6	2.4	--	1.1	0.4	0.3	0.6	6.2
97. HAM, OH	--	0.6	0.5	2.0	0.1	1.0	0.4	0.3	0.5	5.3
98. HAR, PA	--	1.0	0.8	3.6	--	1.7	0.6	0.5	0.9	9.2
99. HUN, WV-KY,OH	--	1.0	0.9	3.5	--	1.7	0.6	0.6	0.9	9.1
100. HUN, AL	--	0.3	0.2	1.0	--	0.5	0.2	0.1	0.9	9.7

TABLE IV-5 (Continued)

	NSC01	NSC02	NSC03	NSC04	NSC05	NSC06	NSC07	NSC08	NSC09	TNSCO
101. JAC, MS	--	1.1	0.9	3.8	--	1.8	0.7	0.6	0.9	9.7
102. JOH, PA	--	1.1	0.9	4.0	--	1.9	0.7	0.6	1.0	10.1
103. KAL, MI	--	0.2	0.2	0.7	--	0.3	0.1	--	0.2	1.7
104. KNO, TN	--	1.7	1.3	5.8	--	2.7	10.	0.9	1.5	15.0
105. LAN, PA	--	1.5	1.2	5.2	--	2.4	0.9	0.8	1.3	13.3
106. LAN, MI	--	0.9	0.7	3.1	--	1.5	0.5	0.4	0.8	7.9
107. LAS, NV	--	1.2	1.0	4.1	--	1.9	0.7	0.7	1.0	10.6
108. LAW, MA-NH	--	0.4	0.3	1.2	--	0.6	0.2	0.1	0.3	3.1
109. LITT, AK	--	0.7	0.6	2.5	--	1.2	0.4	0.3	0.6	6.4
110. LOR, OH	0.1	2.7	2.2	9.5	0.1	4.5	1.7	1.0	2.4	24.1
111. LOW, MA	--	0.1	0.1	0.3	--	0.1	--	--	0.1	0.7
112. MAC, GA	--	0.5	0.4	1.9	--	0.9	0.3	0.3	0.5	4.9
113. MAD, WI	--	0.6	0.5	2.2	--	1.0	0.4	0.3	0.5	5.5
114. MOB, AL	--	1.6	1.3	5.6	--	2.7	1.0	0.9	1.4	14.5
115. MON, AL	--	0.7	0.6	2.6	--	1.2	0.5	0.4	0.7	6.8
116. NEW, CN	--	0.4	0.4	1.4	--	0.7	0.2	0.1	0.3	3.5
117. NEW, CN	--	0.2	0.2	0.9	--	0.4	0.2	0.1	0.2	2.1
118, NEW, VA	--	0.2	0.1	0.6	--	0.3	0.1	--	0.2	1.5
119. ORL, FL	--	1.0	0.8	3.4	--	1.6	0.6	0.5	0.9	8.8
120. OXN, CA	--	1.9	1.5	6.5	--	3.1	1.2	1.0	1.6	16.9
121. PEN, FL	--	1.0	0.8	3.7	--	1.7	0.7	0.6	0.9	9.5
122. PEO, IL	--	0.8	0.7	3.0	--	1.4	0.5	0.4	0.7	7.6
123. RAL, NC	--	0.2	0.1	0.6	--	0.3	0.1	--	0.1	1.4
124. REA, PA	--	1.7	1.4	6.0	--	2.8	1.0	0.9	1.5	15.3
125. ROC, IL	--	1.2	1.0	4.2	--	2.0	0.8	0.7	1.0	10.9
126. SAG, MI	--	1.3	1.0	4.5	--	2.1	0.8	0.7	1.2	11.6
127. SAL, CA	--	1.2	1.0	4.2	--	2.0	0.7	0.6	1.0	10.8
128. SAN, CA	--	1.5	1.2	5.2	--	2.5	0.9	0.8	1.3	13.4
129. SAN, CA	--	1.2	1.0	4.2	--	2.0	0.7	0.6	1.0	10.8
130. SCR, PA	0.1	2.6	2.1	9.2	0.1	4.3	1.6	1.0	2.3	23.3

TABLE IV-5 (Concluded)

	NSCO1	NSCO2	NSCO3	NSCO4	NSCO5	NSCO6	NSCO7	NSCO8	NSCO9	TNSCO
131. SHR, LA	--	1.3	1.1	4.6	--	2.2	0.8	0.7	1.2	11.9
132. SOU, IN	--	0.6	0.5	2.2	--	1.1	0.4	0.3	0.6	5.7
133. SPO, WA	--	1.2	1.0	4.2	--	2.0	0.7	0.7	1.0	10.8
134. STA, CN	--	0.2	0.2	0.7	--	0.3	0.1	--	0.2	1.6
135. STO, CA	--	0.3	0.3	1.1	--	0.5	0.2	--	0.3	2.8
136. TAC, WA	--	1.4	1.2	5.1	--	2.4	0.9	0.8	1.3	13.0
137. TRE, NJ	--	0.6	0.5	2.0	--	1.0	0.4	0.2	0.5	5.2
138. TUC, AZ	--	1.4	1.1	4.9	--	2.3	0.9	0.8	1.2	12.8
139. TUL, OK	--	1.5	1.2	5.1	--	2.4	0.9	0.8	1.3	13.1
140. UTI, NY	--	0.7	0.5	2.3	--	1.1	0.4	0.3	0.6	8.9
141. VAL, CA	--	0.3	0.2	0.9	--	0.4	0.2	--	0.2	2.3
142. WAT, CN	--	0.5	0.4	1.9	--	0.9	0.3	0.3	0.5	4.9
143. WES, FL	--	0.5	0.4	1.7	--	0.8	0.3	0.1	0.4	4.3
144. WIC, KS	0.1	2.9	2.4	10.2	0.1	4.8	1.8	1.4	2.6	26.2
145. WIL, PA	--	2.2	1.8	7.8	0.1	3.7	1.4	1.1	1.9	20.0
146. WIL, DE,NJ,MD	0.1	2.9	2.3	10.0	0.1	4.7	1.8	1.5	2.5	25.9
147. WOR, MA	--	0.7	0.6	2.4	--	1.1	0.4	0.3	0.6	6.2
148. YOR, PA	--	1.0	0.8	3.5	--	1.7	0.6	0.5	0.9	9.0
Total	1.9	84.3	71.4	294.3	1.3	151.7	64.5	58.3	109.2	767.2

TABLE IV-6. GROSS SOILING DAMAGE COSTS BY LARGE SMSA[a]
(million $)

Large SMSA's	GSCO1	GSCO2	GSCO3	GSCO4	GSCO5	GSCO6	GSCO7	GSCO8	GSCO9	TGSCO
1. AKR, OH	--	49.4	0.9	14.3	0.1	4.4	2.8	5.0	2.3	79.3
2. ALB, NY	0.1	57.2	1.3	23.3	0.2	8.4	4.5	6.8	4.5	106.0
3. ALL, NJ	--	42.2	0.8	13.2	0.1	4.2	2.6	4.5	2.3	69.9
4. ANA, CA	--	107.0	2.2	38.9	0.3	13.3	7.5	12.1	7.1	188.0
5. ATL, GA	0.1	103.0	1.8	20.5	0.3	9.5	6.0	10.5	5.0	166.0
6. BAL, MD	0.3	159.0	4.2	78.8	0.6	30.0	14.8	19.7	15.9	324.0
7. BIR, AL	0.2	61.3	1.2	36.1	0.3	14.4	6.8	7.7	7.6	136.0
8. BOS, MA	0.3	212.0	4.5	80.1	0.7	27.9	15.4	24.4	14.8	380.0
9. BUF, NY	0.2	104.0	2.5	45.2	0.4	16.5	8.6	12.5	8.8	199.0
10. CHI, IL	1.3	563.0	15.4	289.0	2.3	111.0	54.5	69.9	59.1	1160.0
11. CIN, OH-KY-IN	--	106.0	2.2	39.4	0.3	13.6	7.6	12.1	7.2	188.0
12. CLE, OH	0.5	174.0	5.8	111.0	0.9	45.1	20.7	22.0	23.9	405.0
13. COL, OH	0.1	67.8	1.2	19.6	0.2	6.0	3.9	6.8	3.2	108.0
14. DAL, TX	0.2	120.0	2.5	43.5	0.4	14.9	8.4	13.6	7.9	212.0
15. DAY, OH	0.1	65.2	1.4	25.8	0.2	9.2	5.0	7.6	4.9	119.0
16. DEN, CO	0.2	100.0	2.7	51.2	0.4	19.6	9.7	12.5	10.1	207.0
17. DET, MI	0.7	326.0	8.9	166.0	1.3	63.8	31.2	40.4	33.8	672.0
18. FOR, FL	--	52.5	0.8	12.1	0.1	3.2	2.5	4.6	1.7	77.5
19. FOR, TX	0.1	58.4	1.1	18.9	0.2	6.2	3.7	9.6	3.3	98.0
20. GAR, IN	0.1	45.0	1.0	16.8	0.1	5.8	3.2	5.2	3.1	80.8
21. GRA, MI	--	38.1	0.6	10.4	0.1	3.1	2.1	3.7	1.6	59.8
22. GRE, NC	--	45.1	0.8	14.0	0.1	4.5	2.8	4.8	2.4	74.6
23. HAR, CT	--	60.8	4.1	16.5	0.2	4.8	3.3	5.9	2.6	95.1
24. HON, HI	--	39.3	0.7	10.8	0.1	3.2	2.1	3.8	1.7	61.8
25. HOU, TX	0.2	147.0	4.8	47.1	0.4	15.2	9.2	15.7	8.1	246.0
26. IND, IN	0.1	82.8	1.4	22.8	0.2	6.8	4.5	8.1	3.6	130.0
27. JAC, FL	--	38.5	0.6	10.3	0.1	3.0	2.1	3.7	1.6	60.0
28. JER, NJ	--	49.8	0.9	15.0	0.1	4.7	3.0	5.2	2.5	81.2
29. KAN, MO-KS	0.1	98.7	1.8	30.7	0.3	9.8	6.0	10.3	5.2	163.0
30. LOS, CA	1.0	606.0	1.4	248.0	2.1	89.2	4.7	71.6	47.3	1,120.0
31. LOU, KY-IN	--	67.8	1.7	32.3	0.3	12.3	6.1	8.1	6.5	133.0
32. MEM, TN-AR	0.1	55.2	1.1	18.3	0.2	6.1	3.6	6.0	3.2	93.7
33. MIA, FL	--	100.0	1.5	23.3	0.2	6.1	4.7	8.9	3.2	148.0
34. MIL, WI	0.1	105.0	2.0	34.4	0.3	11.2	6.7	11.3	6.0	117.0
35. MINN, MN	0.1	133.0	2.2	36.9	0.3	10.9	7.3	13.0	5.9	209.0

a/ $GSCO_i$ denotes the gross soiling damage cost for the ith type of cleaning operation, i = 1, 2,. . ., 9, TGSCO is the sum of $GSCO_i$ over i.

TABLE IV-6 (Concluded)

Large SMSA's	GSCO1	GSCO2	GSCO3	GSCO4	GSCO5	GSCO6	GSCO7	GSCO8	GSCO9	TGSCO
36. NAS, TN	0.1	42.3	1.0	18.0	0.2	6.6	3.4	5.1	3.5	80.1
37. NEW, LA	0.1	76.3	1.3	22.1	0.2	6.8	4.3	7.7	3.6	122.0
38. NEW, NY	0.1	939.0	18.2	317.0	2.8	105.0	61.5	103.0	55.9	1,600.0
39. NEW, NJ	0.3	147.0	3.7	67.1	0.6	25.0	12.7	17.9	13.2	288.0
40. NOR, VA	0.1	47.6	1.1	18.8	0.2	6.7	3.6	5.6	3.5	87.0
41. OKL, OK	--	49.7	0.8	12.3	0.1	3.4	2.5	4.6	1.8	75.1
42. OMA, NE-IA	0.1	42.0	1.1	19.9	0.2	7.5	3.8	5.1	4.0	83.6
43. PAT, NJ	--	99.9	1.4	21.0	0.2	5.0	4.3	8.6	2.7	143.0
44. PHI, PA-NJ	0.3	354.0	6.0	100.0	0.9	30.2	19.8	32.2	16.1	563.0
45. PHO, AZ	0.2	80.5	2.5	48.7	0.4	19.5	9.1	10.1	10.3	181.0
46. PIT, PA	0.4	192.0	4.8	87.8	0.7	32.7	16.6	23.3	17.3	375.0
47. POR, OR-WA	0.1	82.5	1.5	25.4	0.2	8.1	5.0	8.6	4.3	135.0
48. PRO, RI-MA	0.1	67.9	1.2	19.1	0.2	5.7	3.8	6.7	3.1	107.0
49. RIC, VA	0.1	40.4	0.9	15.9	0.1	5.7	3.1	4.7	3.0	73.9
50. ROC, NY	0.1	65.6	1.2	21.1	0.2	6.9	4.1	7.0	3.7	110.0
51. SAC, CA	--	60.3	0.9	13.8	0.1	3.6	2.8	5.3	1.9	88.8
52. SAI, MO-IL	0.3	183.0	4.2	75.8	0.6	27.3	14.4	21.7	14.4	342.0
53. SAL, UT	--	38.7	0.6	13.0	0.1	4.3	2.5	4.2	2.3	66.1
54. SAN, TX	--	57.0	0.8	11.6	0.1	2.7	2.4	4.9	1.4	80.9
55. SAN, CA	0.2	91.9	2.3	42.1	0.3	15.7	8.0	11.1	8.3	180.0
56. SAN, CA	--	99.5	1.4	21.9	0.2	5.5	4.5	8.6	2.9	144.0
57. SAN, CA	0.1	265.0	3.8	59.7	0.6	15.1	12.1	23.1	8.1	388.0
58. SAN, CA	--	75.9	1.1	17.0	0.2	4.3	3.5	6.6	2.3	111.0
59. SEA, WA	--	110.0	1.6	24.0	0.2	5.9	4.9	9.6	3.2	160.0
60. SPR, MC-CT	--	38.9	0.6	9.3	0.1	2.5	1.9	3.5	1.3	58.2
61. SYR, NY	0.1	47.4	1.0	18.3	0.2	6.5	3.4	4.4	3.4	86.0
62. TAM, FL	0.1	88.3	1.5	24.4	0.2	7.2	4.8	8.7	3.9	129.0
63. TOL, OH-MI	0.1	53.3	1.3	22.7	0.2	8.3	4.3	6.4	4.4	101.0
64. WAS, DC-MD-VA	0.2	247.0	4.1	70.1	0.6	22.7	13.6	23.3	12.0	364.0
65. YOU, OH	0.1	40.0	0.9	15.4	0.1	5.4	3.0	4.6	2.9	72.4
Total	9.5	8,063.0	169.8	2,967.8	25.4	1,029.7	531.3	883.8	546.6	14,162.8